Availability Design and Simulation

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Availability design and simulation

- Goal: establish top-level availability requirements for the collider, allocate these requirements down to major collider systems, and investigate feasibility
- Collect data on mean time between failure (MTBF) and mean time to repair (MTTR) of components in existing machines to guide our budgeting process
- Budget a set of MTBFs, MTTRs that give a reasonable overall availability. We allowed 25% downtime total. 10% was kept as contingency, and MTBFs, MTTR's were required to give 15% downtime.
- Write a simulation that given the MTBFs, MTTRs, numbers and redundancies of components, and access requirements for repair can calculate average availability and the integrated luminosity per year. Luminosity is mostly either design or zero in this simulation.
- Iterate as many times as we had time for (one and a half iterations were done) to minimize the overall cost of the LC while maintaining the goal availability
- The linacs and DRs are modeled in detail down to the level of magnets, power supplies, power supply controllers, vacuum valves, BPMs …But, due to time constraints, other regions were simulated as monolithic units.

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The Simulation includes:

1. Effects of redundancy such as 21 DR kickers where only 20 are needed in the cold design or the 3% energy overhead in the warm design
2. Some repairs require accelerator tunnel access, others can't be made without killing the beam and others can be done hot.
3. Time for radiation to cool down before accessing the tunnel
4. Time to lock up the tunnel and turn on and standardize power supplies
5. Recovery time after a down time is proportional to the length of time a part of the accelerator has had no beam. Recovery starts at the injectors and proceeds downstream.
6. Manpower to make repairs can be limited.
7. Opportunistic Machine Development (MD) is done when part of the LC is down but beam is available elsewhere for more than 2 hours.
8. MD is scheduled to reach a goal of 1 - 2% in each region of the LC.

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9. The linacs and DRs are modeled in detail down to the level of magnets, power supplies, power supply controllers, vacuum valves, BPMs …
10. Due to time constraints other regions were simulated as monolithic units.
11. Non-hot maintenance is only done when the LC is broken. Extra non-essential repairs are done at that time though. Repairs that give the most bang for the buck are done first.
12. PPS zones are handled properly (e.g. can access the warm (but not the cold) linac when beam is in the DR. It assumes there is a tuneup dump at the end of each region. (Important design requirement which should not be forgotten.)
13. Kludge repairs can be done to ameliorate a problem that otherwise would take too long to repair. Examples: Tune around a bad quad in the cold linac or a bad quad trim in either damping ring or disconnect the input to a cold power coupler that is breaking down.
14. During the long (3 month) shutdown, all devices with long MTTR's get repaired.

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Results:

- Using nominal present day MTBF’s for components in the main linacs and DR’s, neither option’s reference design can realize the unavailability goal of 15%.
- To achieve the 15% unavailability goal, the MTBF’s of component in the DR’s and main linacs needed to be increased by a factor of about 4.
- For both options, a crude estimate of the cost associated with this reliability upgrade is about 2% of the total project cost.

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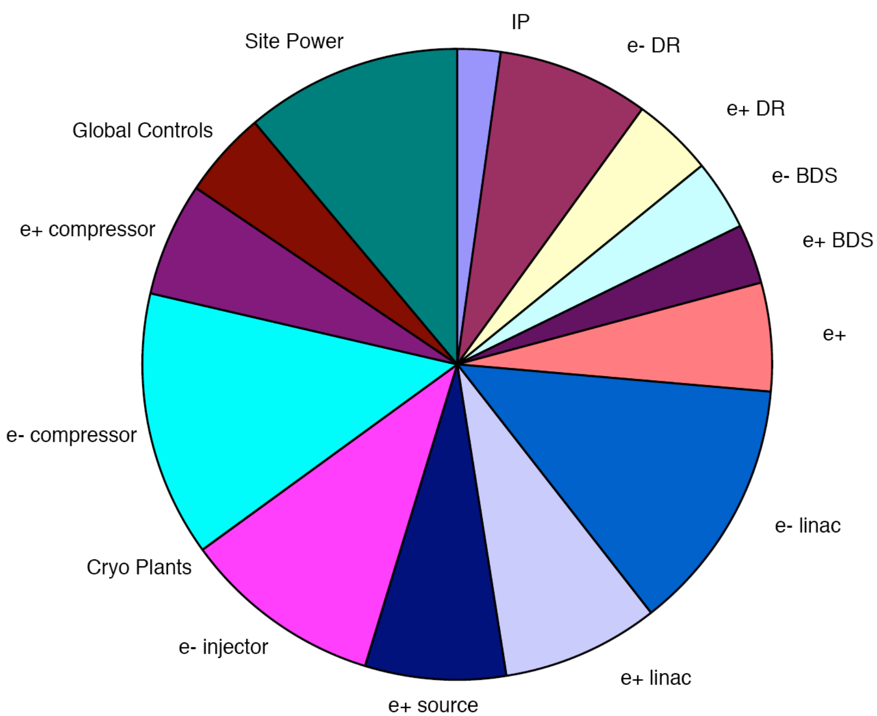
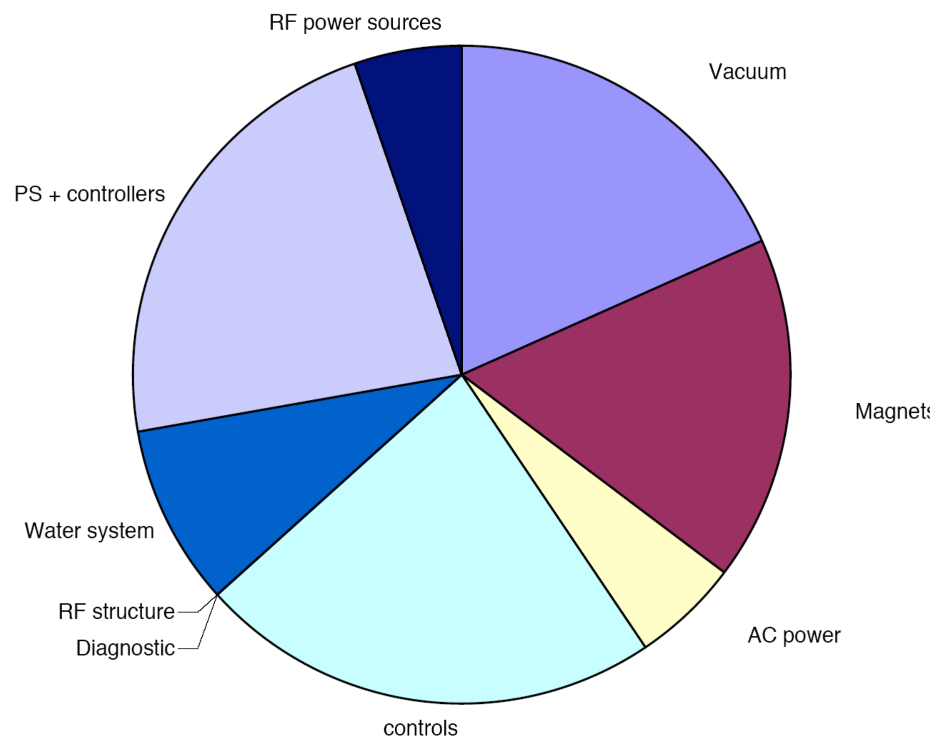


X-band option-improved MTBF's

Downtime by region and system



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Results:

Table 4.4.1.1: Summary of simulation results. Each line represent
was not simulated and hence is only reflected in the table in the cc
A, B, and C are given in Tables 4.4.1.2, 4.4.1.3, and 4.4.1.4. Note t

Run number	LC type	Simulated % time down incl. forced MD	Simulated % time fully up integrating lum or sched MD
Warm1	Warm, 2 tunnel, nominal MTBFs, und e^+	28.1	71.9
Warm2	Warm, 2 tunnel, vers A MTBFs, und e^+	15.0	85.0
Warm3	Warm, 2 tunnel, vers A MTBFs, conv e^+	11.3	88.7
Cold1	Cold, 2 tunnel, nominal MTBFs, und e^+	31.5	68.5
Cold2	Cold, 2 tunnel, vers B MTBFs, und e^+	15.5	84.5
Cold3	Cold 2 tunnel, vers B MTBFs, conv e^+	11.8	88.2
Cold4	Cold 1 tunnel, vers B MTBFs, und e^+	25.1	74.9
Cold5	Cold 1 tunnel vers C MTBFs, und e^+	15.1	84.9

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MTBF improvements needed for cold option ("version B")

Device	Nominal MTBF (hours)	Factor improvement over nominal needed	Source of nominal MTBF	# of devices	Increase in down time (%) if MTBF is 10 x worse
all water cooled magnets	1E6	10	SLAC SLC had 5E5 Fermilab main injector had 2E6	2800	5.0
Large power supply controllers	1E5	40	SLAC SLC had 8E4	600	1.2
Large power supplies	2E5	10	Fermilab main injector had 6E4. TESLA design with redundant regulators estimated at 2E5	600	1.9
All electronics modules	1E5	3	Commonly used number for electronics modules	25000	3.8
Linac controls local backbone	1E5	9	Commonly used number for electronics modules	600	0.8
Vacuum valve controllers	1.9E5	5	SLAC SLC had 1.9E5 for valves + controllers. Most failures were the controllers	300	1.3
Flow switches	2.5E5	10	SLAC SLC had 2.2E5	1700	1.8
Water instrumentation	3E4	3	SLAC SLC had 3.5E4 Fermilab main injector had 5.6E4	330	1.2
AC power distribution small	3.6E5	10	SLAC SLC had 3.6E5	700	1.1
first 5 klystrons and related hardware (should be done with redundancy)	varied	20		10	0.4
Cavity tuner see caption for details	1E6	50	SLAC SLC magnet movers had 5E5. Assume tuner is similar as it is a mechanical stepping motor	18000	0.1
Vacuum pumps on the insulating vacuum	1E5	6	guess	150	1.6
Linac energy overhead	2%	1%	Energy overhead increased from 2% to 3%		5.0

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Variant analysis: Cold Option-1 vs. 2 tunnels:

- With the version B MTBF’s, the cold 1 tunnel simulation gives a downtime of 25%, vs. 15% for the 2 tunnel case.
- To regain 15% downtime, the linac and DR component MTBF’s must be improved by a factor of 3 over the version B MTBF’s, and the energy overhead increased to 8%.
- A crude estimate of the cost of this reliability upgrade is about 3% of the total project cost.

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Variant Analysis: Convention vs Undulator e+ Source:

- Undulator e+ source has much more downtime especially during commission period
  - Availability model indicates that over a few year running period, the annual integrated luminosity could be 18% lower for an undulator positron source as compared to a conventional one.
  - During commissioning, it would be far worse--up to a factor of two.
- Not due to actual source reliabilities (which weren't modeled in detail and were assumed to be the same.)
- Completely due to undulator source needing well tuned high energy electrons.
  - Prevents doing scheduled MD in e.g. e- linac and e+ DR simultaneously
  - During downtime recovery cannot tune e+ system until e- linac is tuned.
  - Can't do opportunistic MD in e+ system while e- is down or being tuned.

Summary-Availability

• Neither of the options was able to reach the required availability using the original estimates for component MTBF and MTTR. In both cases, it was necessary to increase the MTBF's of selected components to fit within the desired 15% hardware unavailability budget. In terms of the reliability improvements needed, there is not a great difference between warm and cold reference designs. Both are very large and complex accelerators where significant effort and expense (~2% of project cost) will be needed to make them reliable enough.

• Use of the one tunnel solution has an impact on the overall reliability of the collider. To fit within the required 15% unavailability budget, the MTBF of many linac and damping ring components must be improved substantially, and the linac energy overhead also must be increased from 2% to 8%.

• Our simulations indicate that the integrated luminosity of the collider built with an undulator-based positron source could be reduced by 20% or so relative to one built with a reliable conventional source during stable operation, and by as much as a factor of two during commissioning.